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Kälin

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(54) **DRIVE DEVICE FOR USE IN A LABORATORY DEVICE**

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H02P 21/06	(2006.01)
H02P 8/14	(2006.01)

(52) **U.S. Cl.**

CPC . ***H02P 21/06*** (2013.01); ***H02P 8/14*** (2013.01)

(58) **Field of Classification Search**

CPC H02P 21/06; H02P 8/14

USPC 422/50, 67; 436/8

See application file for complete search history.

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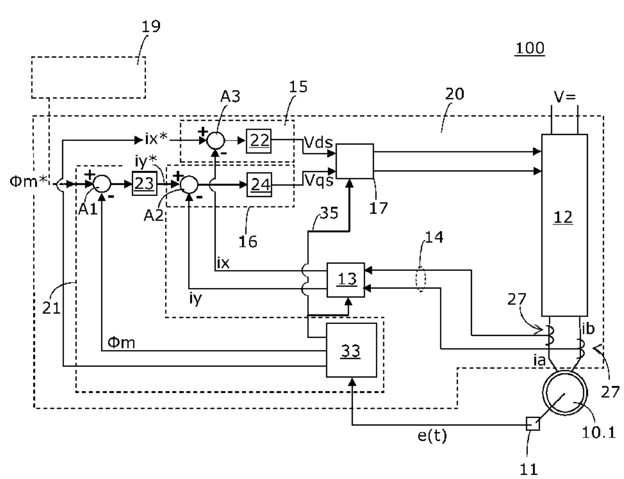
(57) **ABSTRACT**

The invention relates to a drive device (**100**) for use in a laboratory device, having a stepping motor (**10**) having rotor and stator, and having a motor controller (**20**), which is designed for the purpose of activating the stepping motor (**10**). In one embodiment, the drive device (**100**) comprises an encoder (**11**), which supplies a respective current encoder signal (e(t)) in operation (ia, ib), which reflects the current rotor position of the rotor, and phase terminals (**14**, **27**), to tap the currently flowing motor phase currents (ia, ib). The motor controller (**20**) comprises a transformation module (**13**), in order to decompose the currently flowing motor phase currents (ia, ib) using a transformation method into a slip component (ix) and a torque component (iy). Furthermore, it comprises a slip regulation module (**15**), to which the slip component (ix) and a first target value (ix*) are supplied as input variables, and a torque regulation module (**16**), to which the torque component (iy) and a second target value (iy*) are supplied as input variables. The slip regulation module (**15**) and the torque regulation module (**16**) predefine the rotor phase currents (ia, ib) so that the difference between the slip component (ix) and the first target value (ix*) and the difference between the torque component (iy) and the second target value (iy*) are minimal.

16 Claims, 5 Drawing Sheets



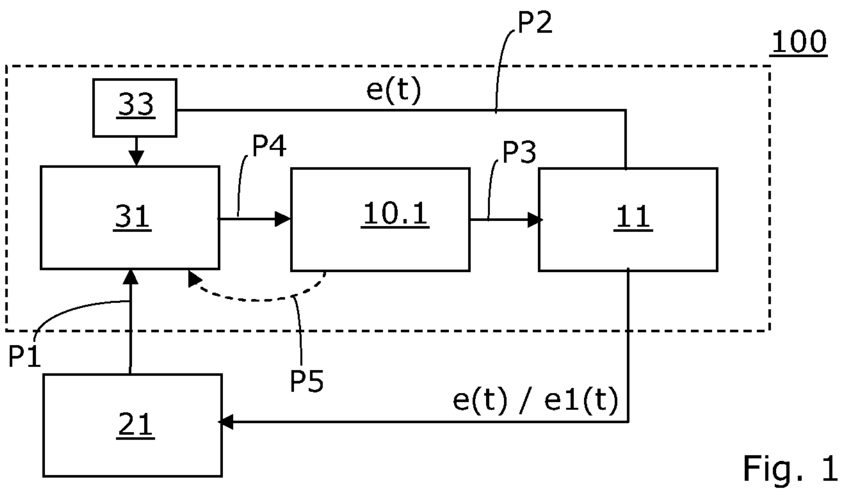

P2
100
33
e(t)
P4
P3
31
10.1
11
P1
P5
21
e(t) / e1(t)

Fig. 1A

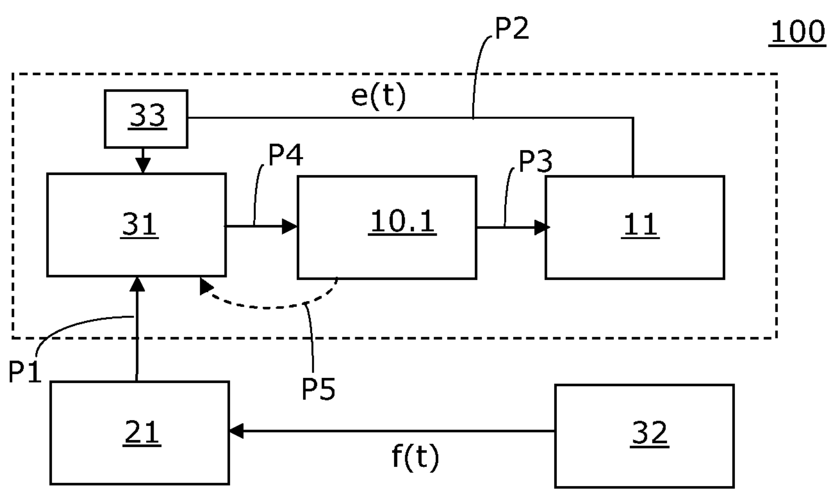
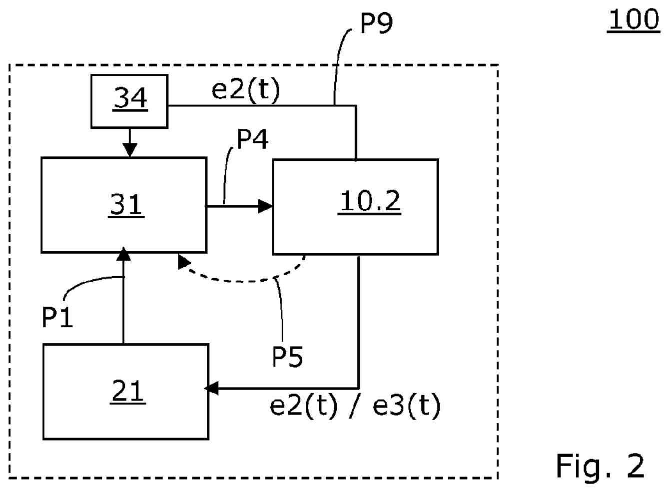
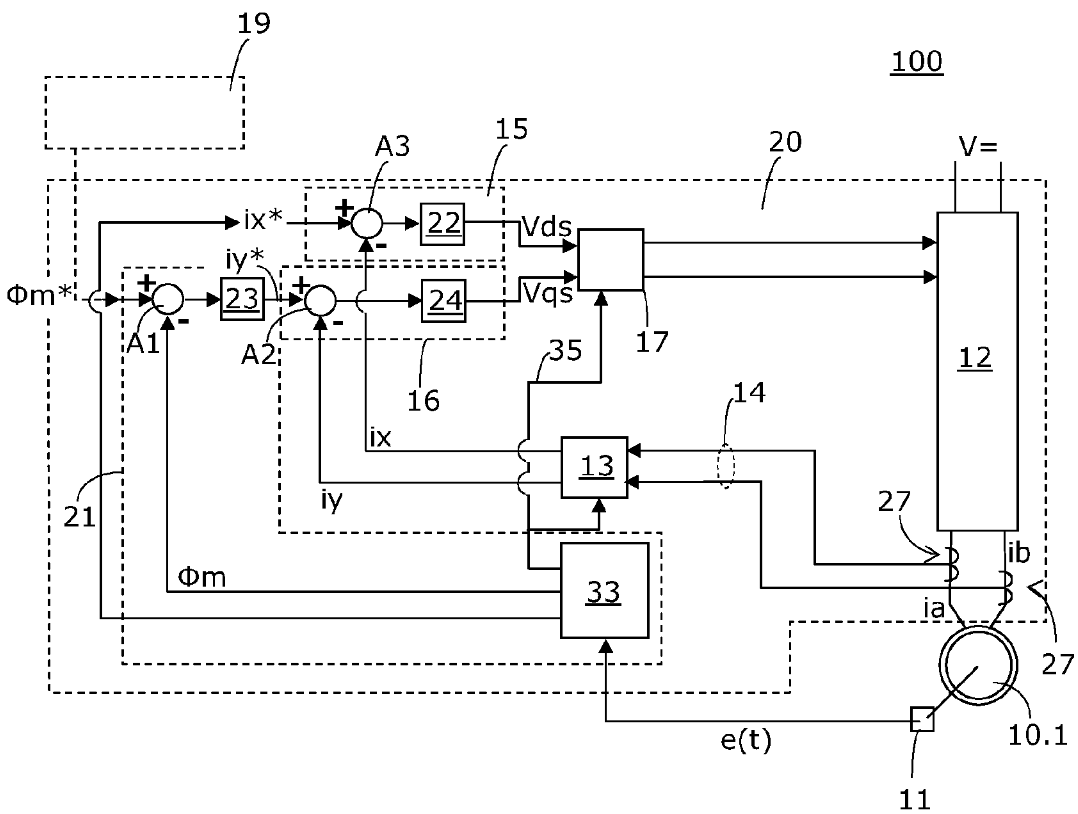

P2
100
33
e(t)
P4
P3
31
10.1
11
P1
P5
21
32
f(t)

Fig. 1B



100
P9
34
e2(t)
P4
31
10.2
P1
P5
21
e2(t) / e3(t)

Fig. 2



19
100
A3
15
20
V=
ix*
22
Vds
iy*
Φm*
23
24
Vqs
A1
A2
17
12
16
35
14
ix
13
27
iy
21
ib
Φm
33
ia
27
10.1
e(t)
11

Fig. 3

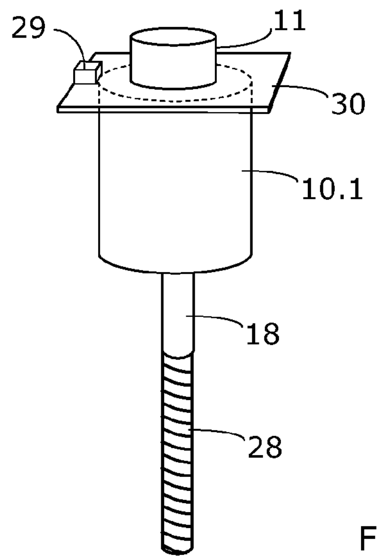


Fig. 4

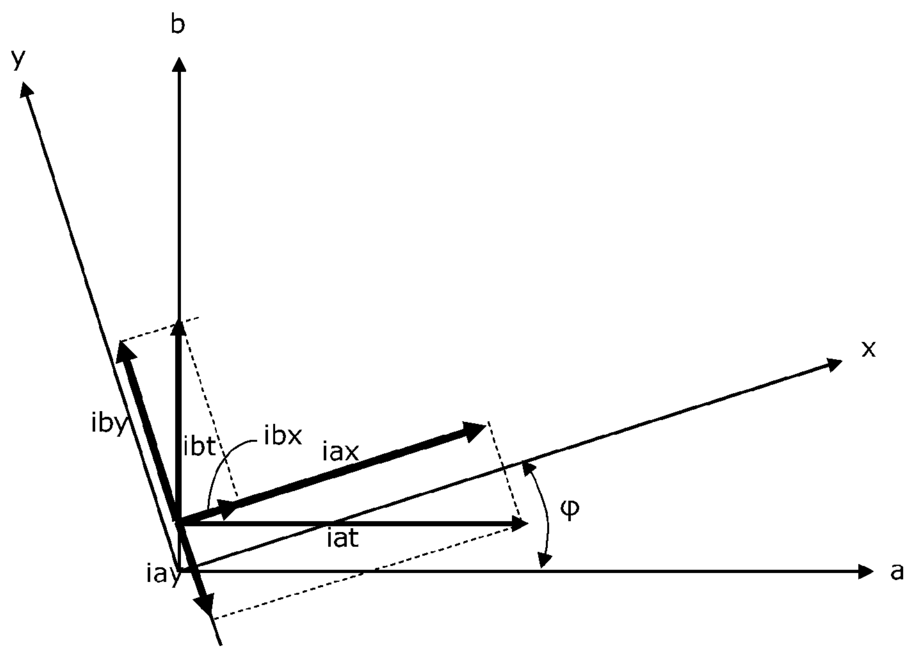


Fig. 5A

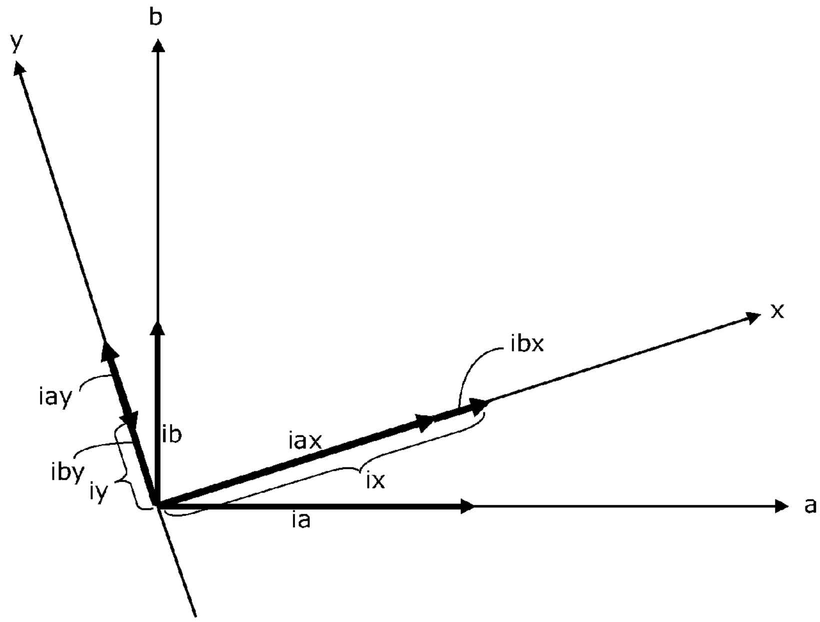

b
y
x
ibx
iay
ib
iax
iby
iy
ix
a
ia

Fig. 5B

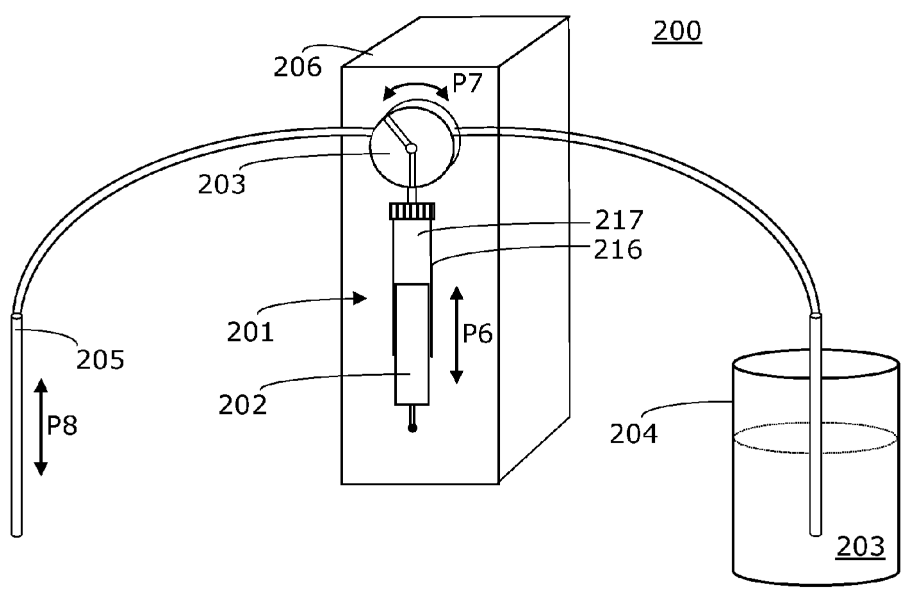

200
206
P7
203
217
216
201
P6
205
202
P8
204
203

Fig. 6

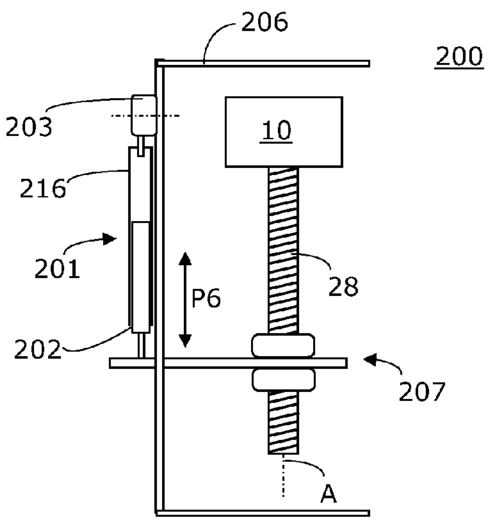


Fig. 7

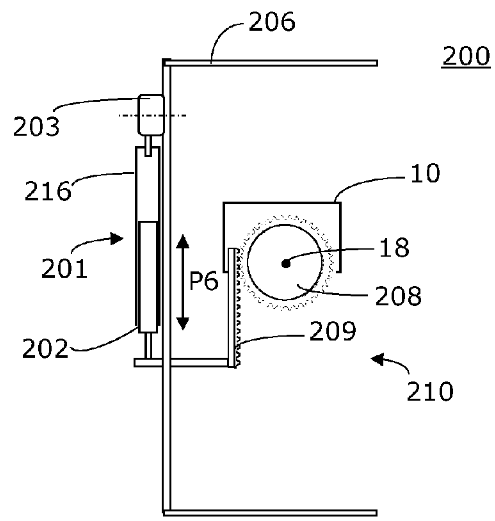


Fig. 8

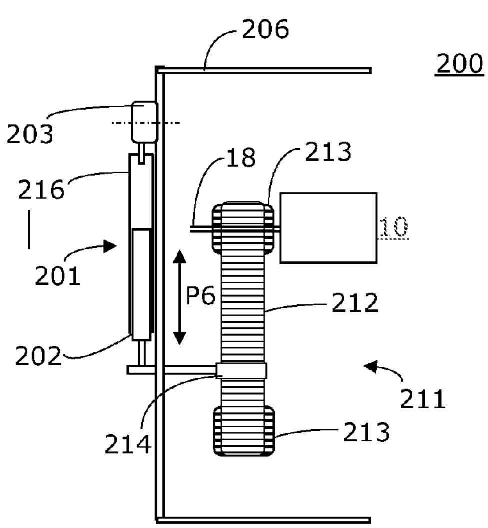


Fig. 9

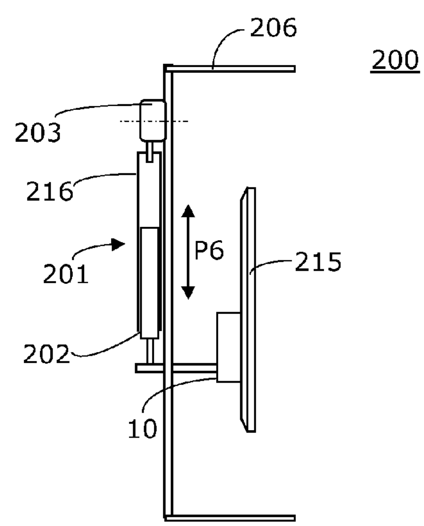


Fig. 10

DRIVE DEVICE FOR USE IN A LABORATORY DEVICE

CROSS REFERENCE TO RELATED APPLICATION

The present application claims priority on U.S. Provisional Patent Application No. 61/321,293 filed Apr. 6, 2010, which is incorporated here by reference.

The invention relates to a drive device for use in a laboratory device. In particular, it is directed to drive devices for liquid-handling laboratory devices, such as diluters and other liquid handling devices.

BACKGROUND OF THE INVENTION

Diluters are frequently used in the laboratory field when liquid quantities must be dispensed precisely. Diluters frequently comprise motor-driven syringe pumps, in which an actuator moves a piston of a syringe up and down precisely. An exemplary diluter is shown in FIG. **6**. A three-way valve can be seated on the syringe, for example, which is also switched over via motor. The valve is preferably rotated so that a syringe chamber and a supply vessel having a reagent or diluent (e.g., a solvent, buffer, or similar medium) are fluidically connected. When the piston is pulled or moved down, the syringe is filled with diluent. The valve is then rotated so that the syringe chamber is fluidically connected to a dispenser tip. Diluent is delivered via the dispenser tip by the motorized raising of the piston. If the piston has reached the very top and the syringe is thus empty, the valve can be rotated in the direction of the supply vessel again and the syringe can be refilled.

In automated pipetting robots, so-called liquid handling devices, up to 16 diluters are used, for example, Freedom EVO® (Tecan Schweiz AG, 8708 Mannedorf, Switzerland) or Biomek® FX (Beckman Coulter, Inc., Fullerton, Calif.). In liquid handling devices, the diluters are used to generate an overpressure or partial vacuum via a line which leads to a pipette tip. The syringe and the line are therefore filled using system liquid. Deionized water is typically used as the system liquid. If the pipette tip is immersed in a sample liquid and a partial vacuum is generated at the pipette tip using movement of the syringe piston, a liquid sample is sucked into the syringe. If an overpressure is generated at the pipette tip via the syringe piston, the previously received liquid sample is delivered again. The diluters used in the liquid handling devices typically have a three-way valve. However, other valves can also be used. With the aid of the valve, fresh system liquid can be sucked in from a supply vessel via the syringes, in order to fill the line between diluter and pipette tip or to flush the line and to clean the pipette tips using system liquid.

During automatic pipetting, a sample is preferably delivered from the air without contact with the target vessel. The risk of sample carryover is thus minimized. In addition, the samples can be delivered more rapidly from the air than in contact with the target vessel or with a liquid already located in the target vessel. In the case of delivery of small volumes from the air, it is very important for the sample to be delivered at high speed and with a sharp stop at the end, in order to thus achieve a large negative acceleration. Otherwise, clean droplet ejection does not occur at the pipette tip. To be able to ensure these speeds having the sharp end stop at the pipette tip, it is important that the movement of the syringe piston is generated as precisely as possible and with high dynamic response, and is transmitted very directly to the pipette tip.

Water, preferably deionized water, in the pipette tip, line, and syringe, is used in liquid handling devices as a rigid movement mediator of the movement of the syringe piston to the pipette tip. The deionized water is considered an incompressible liquid and is therefore very well suitable as a movement mediator. However, if gas bubbles occur in the system liquid, e.g., due to the outgassing of air, every gas bubble acts as a small spring. Gas bubbles can form because of elevated temperatures of a motor in a diluter. The movement mediation from the syringe piston to the pipette tip is damped by such gas bubbles. Mechanical hysteresis effects in the diluter mechanism can also influence the system. This damping has a disadvantageous effect on the pipetting accuracy and correctness of the delivered volumes.

Motors, preferably stepping motors having corresponding motor controllers, are used in a liquid handling device. It has been shown that in the case of the conventional activation of a typical two-phase AC-operated stepping motor, high holding currents occur. These holding currents have the result that the entire diluter heats up. Temperatures of greater than 50° C. have been measured on freestanding diluters. If multiple such diluters are installed adjacent to one another in a liquid handling device, still higher temperatures can even occur, because the heat can only be dissipated poorly. The syringes, the valves, and sometimes the lines also heat up via the diluter housing. The system liquid is thus heated, which results in outgassing of air and therefore the above-mentioned undesirable bubble formation.

In addition, this heating of the motor and the surrounding components can result in a reduction of the lifetime (above all of the electronics and the plastic parts) of the liquid handling device, which is undesirable.

The object therefore results of providing diluters which generate minimal waste heat, do not unnecessarily heat up the system, and therefore do not display bubble formation in the system liquid. The object also results of optimizing other laboratory devices and in particular liquid handling devices. A particularly suitable drive device for this purpose is to be provided. In addition, a corresponding method for activating a motor is to be proposed.

These objects are achieved according to the invention by a device according to the claims. The features of a corresponding laboratory device having at least one drive device according to the invention can also be inferred be inferred.

Proceeding from the findings with respect to the origin of the mentioned temperature problems and the bubble formation in the system liquid in diluters and liquid handling devices, a novel drive device is proposed for use in a diluter, a liquid handling device, or another laboratory device.

According to the invention, the drive device comprises an AC-operated motor, preferably a two-phase AC-operated stepping motor, having rotor and stator, and a motor controller, which is designed to activate the motor dynamically with respect to speed and/or acceleration. The drive device according to the invention comprises means (e.g., a motor-side encoder), which deliver a current signal in operation, which reflects the current position of the rotor in the motor in relation to the stator or the poles. In addition, phase terminals in the form of shunt resistors are provided, for example, to be able to tap the currently flowing motor phase currents on the motor side. The motor controller according to the invention comprises a transformation module, in order to decompose the currently flowing motor phase currents into a slip component and a torque component using a transformation method. Furthermore, it comprises a slip regulation module, to which the slip component and a first target value (e.g., a zero value) are provided as input variables, as well as a torque regulation module, to which the torque component and a second target value are provided as the input variables. The slip regulation module and the torque regulation module regulate the rotor phase currents so that the difference between the slip component and the first target value and the difference between the torque component and the second target value are minimal at all times.

Such a configuration and wiring has the advantage that the motor which is used is always operated in the optimal range (i.e., greater efficiency and lower power consumption). The controllability of the motor is thus substantially improved and the dynamic response of the motor is increased. Dynamic response is understood above all as the capability for rapid acceleration and deceleration. The sharp deceleration is very important for contactless dispensing from the air, as explained at the beginning.

In addition, it is important in the handling of liquids and samples in laboratory devices to always know the precise location of the rotor of the motor. The invention allows a very precise check of the rotor position. Furthermore, it is important to know the precise position of the mechanical elements (for example, the pump piston) for the mentioned devices. This can also be achieved using the drive device according to the invention. In addition, the high dynamic response also plays a role for the pipetting result, as noted. For this purpose, the most rigid possible, undamped system is important, which does not display any spring action. The drive device according to the invention also offers advantages over typical devices in this regard.

Above all, at a standstill, current is only fed into the motor of the drive device when a force is required. Therefore, in a static case, no or only very low holding currents flow and hardly any heat is formed at the motor. Heating of the system liquid and therefore the outgassing of air are thus avoided. The drive device according to the invention is therefore particularly suitable as a drive device for a pump in a laboratory device and especially for a pump in a diluter or another laboratory device.

It is considered to be a further advantage of the invention that, due to the intelligent, demand-dependent feed of the motor, the power consumption is less than in previous devices or laboratory devices. The reduced power consumption has an influence on the ecology of the device or the laboratory device. In addition, applications can be implemented because of the low power consumption, which were not possible using previous approaches. For example, the invention can be used in portable applications, e.g., for environmental analysis or other field applications, which are fed from batteries or regenerative power sources.

The motors which are used here are synchronous motors which follow the externally applied field. Therefore, they can be operated without sensors for position feedback (encoder or rotary encoder). However, in some of the embodiments the invention nonetheless provides a motor-side encoder, to achieve good positioning accuracy, shorten the initialization method, and above all simplify the activation of the motor having the described advantages. In other embodiments which manage without an encoder, a motor is briefly operated in generator operation, in order to obtain information about the rotor position cyclically (e.g., every second current control cycle).

The invention has the advantage that a linear encoder or another decoder is not necessary to ascertain a linear movement of a mechanical component (e.g., a pump piston, tappet, a rotary spindle, or another mechanically movable element). The precise position is preferably accomplished according to the invention by an interaction of a motor-side angle encoder and a position regulation module, or by an interaction of a motor briefly operated in generator operation and a position regulation module.

In order to achieve an accuracy which is suitable for high-precision dosing in a diluter, for example, in which a motor controller according to the invention activates a (stepping) motor used as a pump motor, an encoder which has an angle resolution greater than 1024 lines per revolution can be used.

Depending on the embodiment and demand profile, an additional encoder can be placed on the moving mechanism, in order to also be able to compensate for the mechanical hysteresis, for example.

The use of linear encoders is superfluous, since the motor-side encoder or the motor in generator operation allows precise positioning specification with or without an additional encoder on the mechanism. Therefore, a drive device according to the invention can be integrated easily in greatly varying laboratory devices.

An activator of the motor typically has a processor which interacts with the motor. Only a control connection, for example, via a signal bus (e.g., RS-232, RS-485, or CAN) and a mechanical connection of the shaft or the axis of the (stepping) motor to the mechanical element of the laboratory device to be moved must be produced, in order to be able to address or activate the system (e.g., a processor).

It is a further advantage of the invention that the (stepping) motor is operated more efficiently than in the case of typical drive devices for laboratory devices.

The (stepping) motor has a significantly longer run time (in the meaning of service life or usage duration), since it is always operated at the optimum operating point using load-dependent current.

Through the increased dynamic response of the (stepping) motor using activation according to the invention, it is possible to dispense smaller volumes directly from the air. Liquid handling devices equipped with conventionally activated motors can deliver up to approximately 3 μl without contact from the air (diluter having 1000 μl syringe, pipette outlet 0.8 mm, and sharp stop), without additional units being required, which allow the drop ejection of the liquid sample by an impulse (see also patent application EP 876 219 of the applicant of the present application). Using the activation according to the invention, the contact-free delivery from the air of volumes up to 1 μl is possible without additional apparatus. The dynamic response of the (stepping) motor allows much steeper deceleration ramps than a conventional controller with identical hardware.

The precision and reproduction accuracy of the liquid delivery can be significantly increased by the precise motor regulation of the invention.

In the case of a conventional activator, extremely annoying noises can occur in specific speed ranges, for example, rattling when passing over the poles, which are intolerable in laboratory daily routine. Using the activation according to the invention, these annoying noises can be easily prevented or masked.

Further advantages result from the detailed description.

The device according to the invention, the laboratory device according to the invention, and the method according to the invention will be explained in detail on the basis of schematic drawings of exemplary embodiments, which do not restrict the scope of the invention.

FIG. 1A shows a schematic block diagram of a first drive device of a laboratory device according to the invention;

FIG. 1B shows a schematic block diagram of a second drive device of a laboratory device according to the invention;

FIG. **2** shows a schematic block diagram of a further drive device of a laboratory device according to the invention;

FIG. **3** shows details of a schematic block diagram of a further drive device of a laboratory device according to the invention;

FIG. **4** shows a schematic perspective view of a drive device of a laboratory device according to the invention;

FIG. **5**A shows a schematic view of a first step of the coordinate transformation according to the invention;

FIG. **5**B shows a schematic view of a second step of the coordinate transformation according to the invention;

FIG. **6** shows a schematic perspective view of a pipetting robot having a diluter according to the invention;

FIG. **7** shows a schematic side view of a first diluter according to the invention;

FIG. **8** shows a schematic side view of a second diluter according to the invention;

FIG. **9** shows a schematic side view of a third diluter according to the invention;

FIG. **10** shows a schematic side view of a fourth diluter according to the invention.

Advantageous embodiments of the invention are described hereafter, these being exemplary embodiments. They comprise both various implementations of the overall invention, and also assemblies and individual parts of the invention. Fundamentally, the described assemblies and individual parts of the various embodiments may be combined with one another, or the assemblies and individual parts of individual embodiments may be replaced by the assemblies and individual parts of other embodiments, respectively. The combinations formed in this case can require small adaptations, which are trivial to a person skilled in the art and are therefore not described further, for example, to allow cooperation or interlocking of the assemblies and individual parts.

The term module is used here to indicate a functional group which is implemented in hardware, software, or as a combination of hardware and software. These modules preferably comprise one or more digital signal processors (DSP).

The motors which are used here are identified by the reference sign **10**. Where a differentiation is made between motors with encoder **11** and motors without encoder **11**, the first are identified by **10**.**1** and the second by **10**.**2**. The motors **10**.**1** and **10**.**2** do not have to differ from one another technically, however, but rather the difference is primarily in the wiring and/or activation of the motors **10**.**1**, **10**.**2**.

Two fundamental embodiments of the invention with encoder are shown in schematic block diagrams in FIGS. **1**A and **1**B. Another fundamental embodiment of the invention without encoder (encoder-free embodiment) is shown in a schematic block diagram in FIG. **2**. The function of the individual blocks or modules can also be allocated or combined differently, however, as shown in the figures.

Reference is made at various times to stepping motors **10** in connection with the present invention. The stepping motor **10** is a synchronous motor **10**, in which the stator current is advanced from one set of stator coils to the next set of stator coils. The corresponding commutation is performed electronically in the case of the drive device **100** according to the invention by the use of a motor controller **20** having commutation module **31**, as schematically shown in FIGS. **1**A, **1**B, and **2**. The commutation can also be performed directly by a PID controller and/or other modules (this form of commutation is not shown in the figures). The magnetic attraction between rotor and stator teeth and the continuous commutation result in a rotational movement of the rotor.

In general, this activation can be applied with any type of synchronous motors **10**. However, stepping motors **10** are preferably used in all embodiments here. Stepping motors **10** which have a step width less than 2° and preferably less than 1° are very particularly suitable. The smaller the step width, the better the controllability.

A stepping motor **10** is a motor whose rotor precisely follows the externally applied stator field. It can therefore also be operated without sensors for position feedback (encoder **11** or rotary encoder). Motors **10**.**2** which are briefly operable in generator operation to thus allow feedback about the rotor position, can also be operated without sensors for position feedback (encoder **11** or rotary encoder) by utilizing the back-EMF effect.

According to the invention, in some of the embodiments, a motor **10**.**1** having motor-side encoder **11** is used, as shown in FIGS. **1**A, **1**B, and **3**. This encoder **11** is seated directly on or adjacent to the motor **10**.**1** and supplies a signal, an encoder signal e(t) here, to the commutation module **31** (via an interconnected module for encoder signal processing **33** here). In addition, the encoder **11** can also transmit the encoder signal e(t) or a signal **e1**(*t*), which was derived from the encoder signal e(t) or ascertained therefrom, to a position regulation module **21**, as shown in FIG. **1**A. Alternatively, as shown in FIG. **1**B, an additional (separate) encoder **32** is used, which is seated on or adjacent to a moving mechanical element (e.g., a mechanical element of a pump) of the drive device **100**, for example. This encoder **32** supplies an encoder signal f(t) to the position regulation module **21**. A combination of the two embodiments of FIGS. **1**A and **1**B is also conceivable, in which both the encoder **11** on the motor **10**.**1**, and also a further encoder **32** transmit encoder signals e(t) or **e1**(*t*) and f(t) to the position regulation module **21**.

However, the activation according to the invention may also be applied without encoder, in that the so-called back-EMF effect (also known as the electromotive counterforce or counter electromotive force) of a motor **10**.**2** is utilized. The corresponding embodiments do not require a motor-side encoder **11** to allow a statement about the rotor position, as indicated on the basis of the very schematic block diagram in FIG. **2**. A motor **10**.**2** whose back-EMF is used is employed and activated by a commutation module **31** so that it primarily operates as a motor **10**.**2** and absorbs electrical power, to convert this power into mechanical movement (in the form of a rotation). However, the motor **10**.**2** is briefly operated as a freewheeling generator, which converts the rotation of the motor **10**.**2** into a voltage/current (referred to as generator signal **e2**(*t*) here). The embodiments of the invention which use an encoder-free motor **10**.**2** instead of a motor **10**.**1** having encoder **11** use the short-term generator operation of the motor **10**.**2** to allow a statement about the rotor position. The voltage (referred to as generator signal **e2**(*t*) here), which is tapped at the motor windings (on the rotor), while the motor **10**.**2** briefly continues to rotate in generator operation, is proportional to the angular velocity of the rotor. The rotor position in relation to the stator can be ascertained on the basis of the voltage curve. During the short-term generator operation, the rotor of the motor **10**.**2** continues to rotate at nearly unchanged angular velocity. During the motor operation, a current signal **e2**(*t*) is not available. The current signal **e2**(*t*) is only provided during the short-term generator operation, but can be tracked using a model which is modulated in software. The signal **e2**(*t*) or a signal **e3**(*t*), which is derived from the signal **e2**(*t*) or ascertained therefrom, can optionally also be supplied to a position regulation module **21**. It contains the same information as the encoder signal.

The position regulation module **21** (see FIGS. **1**A, **1**B, **2**, and **3**) acts on the commutation module **31**, as shown by the arrow P**1**. A connection P**2** is used as feedback between the encoder **11** or the motor **10.2** and the commutation module **31**. In the embodiment according to FIG. **2**, a connection P**9** is used as feedback. The tapping of the motor position by the motor-side encoder **11** is shown in FIGS. **1**A, **1**B, and **3** by the arrow P**3**. The commutative activation of the motor **10.1** is symbolized in FIGS. **1**A, **1**B, and **2** by the arrow P**4**.

In addition to the mentioned encoder signals e(t), e**1**(*t*), the commutation module **31** preferably also processes phase currents which are measured on the motor **10.1** or **10.2** or tapped via phase terminals **27**, as shown in FIG. **3**, for example.

Further details on the tapping of the phase currents and an embodiment having motor-side encoder **11** can be inferred from FIG. **3**.

Precise positioning is brought about in some embodiments of the invention by interaction of the motor-side encoder **11** and the position regulation module **21**, or the additional encoder **32** and the position regulation module **21**, respectively. It is also possible, as noted, to have two encoders **11** and **32** interact jointly with the position regulation module **21**.

According to the invention, two-phase AC-operated stepping motors **10** are preferably used in all embodiments, since these motors **10** can be operated at a slow speed (e.g., less than 400 RPM), since they generate high torques, have minimal wear, and are cost-effective above all.

As shown on the basis of a schematic example in FIG. **4**, the (stepping) motor **10** comprises a shaft (axis) **18**, which is connected to a rotor mounted so it is rotatable. Since the stepping motor **10** with the motor controller **20** is primarily designed for use in a diluter **200** or another liquid-handling laboratory device (e.g., a liquid handling device), a mechanical element (e.g., a pump piston **202**, a piston rod, a rotating spindle **28**, a tappet, a gearwheel **208**, a toothed roller or wheel **213**) of a pump is connected to the shaft **18**. Preferably, such pumps comprise a cylinder **216** having a piston **202** movable therein, as shown as an example in FIGS. **6** to **10**. The axis or shaft **18** of the (stepping) motor **10** is mechanically connected to a movable mechanical element of the pump for the driving thereof.

The invention can also be used in connection with gearwheel pumps, screw pumps, diaphragm pumps, or peristaltic pumps. Further details on the possible pump configurations and constructions can be inferred from FIGS. **7** to **10**.

According to the invention, the (stepping) motors **10** are operated in a closed control loop (closed loop), as described in greater detail hereafter. It is taken into consideration that in the case of a motor **10.1**, the encoder information (e.g., the signal e(t)), or in the case of a motor **10.2**, the generator signal e**2**(*t*), and the measured or tapped phase currents are used for the commutation of the motor **10.1** or **10.2**. This commutation is performed, for example, by the commutation module **31**.

The motor controller **20** for the commutation of the motor **10** comprises at least one PI or PID controller. A PI controller is a proportional-integral controller and a PID controller is a proportional-integral-derivative controller. The controllers **22**, **23**, **24** which are used according to the invention operate using a difference between an actual value and a target value. They attempt by regulating the motor controller **20** to minimize this difference or these differences or bring them entirely to zero.

The motor controller **20** preferably comprises three PI controllers or PID controllers **22**, **23**, **24**, as shown in FIG. **3** on the basis of a special embodiment. These PI controllers or PID controllers **22**, **23**, **24** are elements of the corresponding slip regulation module **15**, the corresponding position regulation module **21**, and the corresponding torque regulation module **16**.

The motor controller **20** of the invention is designed so that a rotary field is predefined using the stator coils in such a way that the rotary field follows the rotor of the (stepping) motor **10** with optimum slip. Small deviations from the ideal slip are immediately corrected by the slip regulation module **15** and the torque regulation module **16**, which are responsible for the commutation together.

Further details of an embodiment of the device **100**, which is especially designed for use in a laboratory device, are shown in above-mentioned FIG. **3**. The device **100** comprises a two-phase AC-operated stepping motor **10.1** having rotor and stator here, as well as a motor controller **20**, which is designed to efficiently activate the stepping motor **10**. The device **100** further comprises a motor-side encoder **11**, which supplies a current encoder signal e(t) in each case, which indicates the current rotor position of the rotor of the motor **10.1**. In addition, phase terminals **27** and lines **14** are provided to be able to tap the currently flowing motor phase currents ia, ib on the motor side.

The motor controller **20** is distinguished in all embodiments in that it comprises a transformation module **13**, to decompose the currently flowing motor phase currents ia, ib using a transformation method into a slip component ix and a torque component iy. Preferably, matrix transformation is used as the transformation method. Through the transformation, the current values of a first a-b coordinate system are mapped on a second x-y coordinate system. A slip regulation module **15** is used, to which the slip component ix and a so-called first target value ix* as a reference value are provided as input variables. Furthermore, the motor controller **20** comprises a torque regulation module **16**, to which the torque component iy and a second target value iy* as a reference value are provided as input variables. The slip regulation module **15** and the torque regulation module **16** set the motor phase currents ia, ib in such a way that the difference between the slip component ix and the first target value ix* and the difference between the torque component iy and the second target value iy* are minimal or equal to zero at all times. Furthermore, a module **33** (module for encoder signal processing) is used here, which converts the electrical signals of the encoder **11** (in the concrete case 1024 lines, or **4096** increments per revolution) into an angle ϕm.

In FIG. **3**, addition elements A**1**, A**2**, A**3** are shown by circles and the respective sign applied is indicated by a plus sign or a minus sign directly adjacent to these addition elements A**1**, A**2**, A**3**. The addition element A**1** subtracts the actual position ϕm from the target position ϕm*, i.e., the difference between the target position ϕm*and the actual position ϕm is observed. The addition element A**2** subtracts the torque component iy from the second target value iy*, i.e., the difference between the second target value iy* and the torque component iy is observed. The addition element A**3** subtracts the slip component ix from the first target value ix*, i.e., the difference between the first target value ix* and the slip component ix is observed.

A module **12** for pulse-width modulation can be used, as shown in FIG. **3**, which is supplied with a DC voltage V= and modulates the motor phase currents ia, ib. The DC voltage V=can be 24 V, for example. The mentioned module **33** (module for encoder signal processing) can be used here to convert the electrical signals of the encoder **11** into an angle ϕm. In the case of an encoder-free motor **10.2**, another module **34** (module for generator signal processing) can perform any conversion or preprocessing of the generator signal e**2**(*t*), as indicated in FIG. **2**.

In all embodiments of the invention, the position regulation is particularly important, which is schematically illustrated by a position regulation module **21**. The position regulation module **21** processes, depending on the embodiment, an encoder signal (e.g., e(t)) of a motor **10.1** or a generator signal e**2**(*t*) of a motor **10.2**. A module for encoder signal processing **33** or a module for generator signal processing **34** is preferably interconnected, as shown in FIGS. **1**A, **1**B, **2**, and **3**.

The module for encoder signal processing **33** can be used as part of the motor controller **20**, in order to derive a speed statement from the signal e(t) of the encoder **11**. The speed statement results, for example, from the number of the angle increments, which the encoder **11** indicates, and the time. The speed statement can also be ascertained using an additional encoder **32** (see FIG. **1**B, for example). The speed statement can be an angular velocity of the shaft or axis **18** of the stepping motor **10** or a linear velocity of a moving mechanical element (e.g., the pump piston **202**) of a pump. This speed statement can additionally be supplied to the slip regulation module **15** and/or a higher-order controller of the laboratory device, as shown in FIG. **3** by the connection **35**. This function block or this connection **35**, respectively, is optional.

An optional profile generator **19** is used, which predefines the time-dependent target values ϕm* for the position controller. In the case of a speed controller instead of the position controller **23**, it predefines time-dependent target values for the speed controller. The target value(s), which are each identified by a "*", can also be predefined by application software or an application (e.g., a laboratory device, such as a liquid handling device).

The encoder **11** is preferably an incremental encoder. The higher the resolution of the encoder **11**, the more precisely can target positions ϕm* be approached and also held. To achieve an accuracy which is suitable for the high-precision handling of a liquid quantity in a diluter **200**, for example, in which a motor controller **20** according to the invention activates a (stepping) motor **10.1** used as a pump motor, an encoder **11** which has an angle resolution greater than 1024 lines is used.

A Hall sensor is particularly suitable as an encoder **11**, since such a Hall sensor can be placed in a contactless way on the rear side of a stepping motor **10.1**, for example. A schematic example of a stepping motor **10.1** having a Hall sensor used as an encoder **11** is shown in FIG. **4**. It may also be seen on the basis of this FIG. **4** that the shaft or axis **18** of the motor **10.1** (or a motor **10.2**) can be mechanically connected to a coaxial rotary spindle **28**. The rotary spindle **28** can move a piston **202** or another mechanical element of a pump, for example. In FIG. **4**, it is further indicated that a card **30** or circuit board can be seated on the rear side of the motor **10.1** (or the motor **10.2**) (this card **30** or circuit board on the rear side of the motor **10.1** or **10.2** is optional). A part or all components of the motor controller **20** can be situated on the card **30** or circuit board. The connection to a higher-order controller, e.g., of a laboratory device, can be performed via a plug or a plug connection **29**, for example. The laboratory device can thus be connected with respect to control to the motor controller **20**.

In order that the method of the invention can be applied, the mechanical rotational angle must be uniquely synchronized with the electrical field which is applied to the motor **10**. This can be implemented using an initial, controlled movement. During the initialization movement, the encoder signal e(t) or the generator signal e**2**(*t*) is input and brought into relation with a control signal P**4**. The zero position can then be calculated on the basis of the relation.

According to the invention, the following method is used when activating the (stepping) motor **10.1** or **10.2**.

First step: measuring or tapping the current motor phase currents ia, ib using phase terminals **27** or other means.

Second step: mapping or converting these motor phase currents ia, ib into a two-axis coordinate system having the axes a and b, as shown in FIG. **5**A. The corresponding values iat and ibt represent time-variant values, which were derived from the motor phase currents ia, ib.

Third step: rotating the two-axis a-b coordinate system to adapt it to the current slip of the stepping motor **10**. A transformation angle cp can be used for the rotation of the two-axis a-b coordinate system, which has been obtained during a last iteration of the motor controller **20**. In this third step, the values iat and ibt are decomposed vectorially into coordinate components (vector components) of the x-y coordinate system newly obtained by rotation. The newly obtained x-y coordinate system is defined by the axes x and y, as shown in FIG. **5**A. The vector iat in the a-b coordinate system is decomposed into a component iax on the x axis and a component iay on the y axis. The vector ibt in a-b coordinate system is decomposed into a component ibx on the x axis and a component iby on the y axis. FIG. **5**B shows that the vector ix (=slip component) is composed in the y axial direction from the component iay+iby. The vector iy (=torque component) in the y axial direction, in contrast, is composed of the components iay+iby. The corresponding axes a and b, as well as x and y, are each perpendicular to one another and the vectors on the individual axes are therefore orthogonal to one another, i.e., they are independent of one another. Therefore, if needed the vector ix (=slip component), for example, can be forced to zero, for example, without influencing the current vector iy (=torque component).

This third step is referred to as a transformation or matrix transformation and is performed by the transformation module **13**.

Fourth step: in this step, the corresponding differences (ix*−ix or iy*−iy) are calculated by the addition elements A**3** or A**2**, respectively, as described. The difference ix*−ix controls or regulates the slip component and the difference iy*—iy controls or regulates the torque component. These differences (ix*−ix or iy*−iy) are transmitted as input variables to the controllers **22** or **24**, respectively. The controllers **22** and **24** generate the corresponding voltage vectors Vds and Vqs. To be able to provide the corresponding voltage vectors Vds and Vqs, a transformation is again performed here. A so-called inverse matrix transformation is preferably used for this purpose, which provides a transfer of the vectors of the x-y coordinate system into an a-b coordinate system (in a reversal of the procedure of FIGS. **5**A and **5**B). This inverse matrix transformation is executed by an inverting transformer **17** (see FIG. **3**).

Fifth step: these steps are now each repeated using new values. The higher the repetition rate, the more rapidly the control loop of the motor controller **20** operates. The motor controller **20** regulates the motor **10.1** or **10.2** in quasi-real-time. Ultrasmall deviations are recognized on the basis of the mentioned differentiation and immediately corrected (minimized).

Using the motor controller **20**, the low-pass and magnetic flux properties of the (stepping) motor **10.1**, **10.2** can be compensated for, in order to be able to predefine a speed-independent torque of the (stepping) motor **10.1**, **10.2**.

The drive device **100** can be used particularly advantageously in diluters **200**, as shown in FIGS. **6** to **10**, for example.

A corresponding diluter **200** is shown in FIG. **6**. The diluter **200** comprises a motor-driven syringe pump, in which a motor **10** (not shown in FIG. **6**) moves a piston **202** of a syringe **201** up and down precisely in a cylinder **216**. The up-and-down movement is identified by the double arrow P**6**. For example, a three-way valve **203** (or another valve) can be seated on the syringe **201**, which is also changed over via motor by rotation, as shown by the double arrow P**7**. The valve **203** is preferably switched so that a syringe chamber **217** and a supply vessel **204** are fluidically connected to a reagent or diluent **203** (e.g., a solvent, buffer, or similar medium). When the piston **202** is pulled or moved down, the syringe **201** is filled with diluent **203**. The valve **203** is then switched by rotation, so that the syringe chamber **217** is fluidically connected to a dispenser tip **205**. Diluent medium **203** is delivered via the dispenser tip **205** by moving up the piston **202** via motor. If the piston **202** has reached the very top and the syringe **201** is thus empty, the valve **203** can be switched back in the direction of the supply vessel **204** and the syringe **201** can be refilled. The double arrow P**8** indicates that the dispenser tip **205** can be automatically moved by a robot arm (not shown), for example.

The described up-and-down movement piece **6** of the piston **202** can be brought about by a motor **10**, which is activated and regulated by a motor controller **20**, as described. The motor **10** including motor controller **20** is preferably seated behind or in the interior of the housing **206** shown in FIG. **6**.

Multiple examples of the construction of a diluter **200** with (stepping) motor **10** are shown in FIGS. **7** to **10**.

FIG. **7** shows a diluter **200** having a motor **10** installed at the rear, whose shaft or axis is designed as a rotary spindle **28**. The rotary spindle **28** is seated in a carrier or armature **207**. When the motor **10** rotates the rotary spindle **28** around its longitudinal axis A, the carrier or armature **207** is moved together with the pump piston **202** mechanically connected thereto. The up-and-down movement of the piston **202** is shown by the double arrow P**6**. The other elements of the diluter **200** were already described in connection with FIG. **6**. Reference is therefore made to the description of this figure.

FIG. **8** shows a diluter **200** having a motor **10** installed at the rear, on whose shaft or axis **18** a gearwheel (a spur gear **208** here) is seated. The spur gear **208** engages in a toothed rack **209**. When the motor **10** rotates the axis or shaft **18**, the spur gear **208** also rotates. During a rotation of the spur gear **208** clockwise, the toothed rack **209** is moved upward together with the pump piston **202** connected thereto. During a rotation counterclockwise, a downward movement results. The up-and-down movement of the piston **202** is shown by the double arrow P**6**. In addition to the configuration shown, there are also other forms of so-called gearwheel drives **210** which can be used in a diluter **200**.

FIG. **9** shows a diluter **200** having a motor **10** installed at the rear having toothed belt drive **211**. A toothed roller or a toothed wheel **213** is seated on the shaft or axis **18** of the motor **10**. A second toothed roller or a second toothed wheel **213** is attached at a certain distance. A toothed belt **212** runs around the toothed rollers or wheels **213**. When the motor **10** rotates the axis or shaft **18**, the toothed belt **212** moves. A carrier **214**, for example, which transmits the movement of the toothed belt **212** to the pump piston **202**, is attached to the toothed belt **212**. An up-and-down movement P**6** thus again results.

In the various examples of FIGS. **7** to **9**, step-up or step-down transmissions (e.g., via toothed belts or gearings) can additionally also be used.

FIG. **10** shows a diluter **200** having a linear motor **10** installed at the rear, which comprises an oblong stator **215**. A movement upward or downward results through suitable change of the fields between the linear motor **10** and the stator **215**. This movement can be mechanically transmitted to the pump piston **202**, as shown. An up-and-down movement P**6** again thus results.

A pump which is driven using a drive device **100** has a high efficiency. The high-precision positioning using the position regulation module **21**, the rigid undamped regulating system, and the other features of the invention allow outstanding handling of ultrasmall liquid quantities. In spite of this high accuracy during the handling of ultrasmall liquid volumes, such a pump can be operated at high speed and load-dependent output. The drive device **100** according to the invention can drive a pump at up to 6000 RPM, for example. Because of these properties, such a pump having drive device **100** can be used for manifold different laboratory applications in the corresponding laboratory devices.

Because of the negligible heat development, the drive device **100**, or the diluters **200** having the corresponding drive devices **100**, can be placed closely adjacent to one another, without thermal problems occurring. In particular, this relates to multichannel liquid handling devices having one diluter **200** per pipetting channel for receiving and delivering liquid samples. Each diluter **200** comprises a drive device **100** according to one of the embodiments in this case.

Because of the reduced power consumption, the drive device **100** is particularly also suitable for mobile uses and applications.

Reference numerals:	
stepping motor/synchronous motor	10
encoder	11
pulse-width modulation module	12
transformation module (park transformer)	13
signal lines	14
slip regulation module	15
torque regulation module	16
inverting transformer	17
motor shaft or axis	18
profile generator	19
motor controller	20
position regulation module	21
PI or PID controller	22
PI or PID controller	23
PI or PID controller	24
phase terminals (shunts)	27
rotary spindle	28
plug or plug connection	29
card	30
commutation module	31
further encoder	32
module for encoder signal processing	33
module for generator signal processing	34
connection	35
drive device	100
diluter	200
syringe	201
piston	202
system liquid	203
supply vessel	204
dispenser tip	205
housing	206
carrier/armature	207
spur gear	208
toothed rack	209
gearwheel drive	210
toothed belt drive	211
toothed belt	212
toothed rollers or wheels	213
carrier	214
oblong stator	215
cylinder	216
syringe chamber	217
longitudinal axis	A

-continued

Reference numerals:	
axes, phase currents	a, b
addition elements	A1, A2, A3
axes, torque and slip	y, x
(encoder) signal	e(t), f(t)
signal which was derived from an encoder signal	e1(t)
generator signal	e2(t)
signal which was derived from a generator signal	e3(t)
motor phase currents	ia, ib
time-variant values	iat, ibt
component	iax
component	ibx
component	iay
component	iby
slip component (vector)	ix
first target value, slip	ix*
torque component (vector)	iy
second target value, torque	iy*
transformation angle	φ
arrow	P1, P2, P3, P4, P5, P6, P7, P8, P9
output signals (voltage vectors)	VAs, VBs
DC voltage	V=
target position	Φm*
actual position	Φm

The invention claimed is:

1. A drive device being designed for a laboratory device, comprising

a motor with rotor and stator;

a position acquisition means;

a plurality of phase terminals; and

a motor controller, arranged for controlling the motor, comprising a transformation module, a slip regulation module connected to the position acquisition means, and a torque regulation module connected to the position acquisition means,

wherein the motor controller further comprises a non-transient computer readable medium programmed with a computer software to control one or more digital signal processes to:

direct the position acquisition means to supply a current signal which indicates the current rotational position of the rotor in relation to the stator and further supply a first target value and a second target value,

direct the phase terminals to tap multiple currently flowing motor phase currents on the motor side

direct the transformation module to decompose the currently flowing motor phase currents into a slip component and a torque component using a transformation method,

direct the slip regulation module and the torque regulation module to predefine rotor phase currents for commutation of the motor so that the difference between a slip component value and the first target value and the difference between a torque component value and the second target value are minimal,

wherein the slip component and the first target value are provided as input variables to the slip regulation module,

wherein the torque component and the second target value are provided as input variables to the torque regulation module.

2. The drive device according to claim **1**, wherein an encoder acts as the position acquisition means, wherein the encoder is assigned to the motor, and wherein the current signal is an encoder signal.

3. The drive device according to claim **1**, wherein the motor is an encoder-free stepping motor which is adapted for short-term power generation to thereby generate a current signal comprising information about the rotor position by utilizing the back-EMF effect of the motor.

4. The drive device according to claim **1**, wherein the motor controller further comprises an inverting transformer configured to transform output signals of the slip regulation module and the torque regulation module into control variables, and a pulse-width modulation module configured for converting said control variables into the motor phase currents.

5. The drive device according to claim **1**, wherein the transformation module comprises a matrix transformer.

6. The drive device according to claim **5**, wherein the matrix transformer generates the slip component and the torque component from current values using a matrix transformation.

7. The drive device according to claim **1**, wherein the motor controller modulates the motor phase currents being dependent on the difference between the slip component (ix) and the first target value and the difference between the torque component and the second target value respectively.

8. The drive device according to claim **1**, wherein the motor controller regulates the motor phase currents to zero, if no external forces are applied to the motor.

9. The drive device according to claim **8**, wherein the drive device is designed for installation in a diluter.

10. The drive device according to claim **1**, wherein a position regulation module ascertains an actual rotor position on the basis of the current signal, and is further configured to set the torque of the motor so that the difference between the target position and the actual position is minimal.

11. The drive device according to claim **1**, wherein the motor controller regulates the slip component and the torque component individually and independently of one another.

12. The drive device according to claim **1**, wherein the motor controller compensates for low-pass and magnetic flux properties of the motor, in order to thus be able to predefine a speed-independent torque of the stepping motor.

13. The drive device according to claim **1**, wherein the motor controller comprises an integrated circuit.

14. The drive device according to claim **1**, wherein the motor controller is a pump controller and the motor is a pump motor.

15. The drive device according to claim **1**, wherein the rotor of the motor is mechanically connected to a moving pump element of a laboratory device.

16. A laboratory device comprising at least one drive device according to claim **1**,

wherein the at least one drive device of said laboratory device is connected to said motor controller, and

wherein the laboratory device is controlled by said motor controller.

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